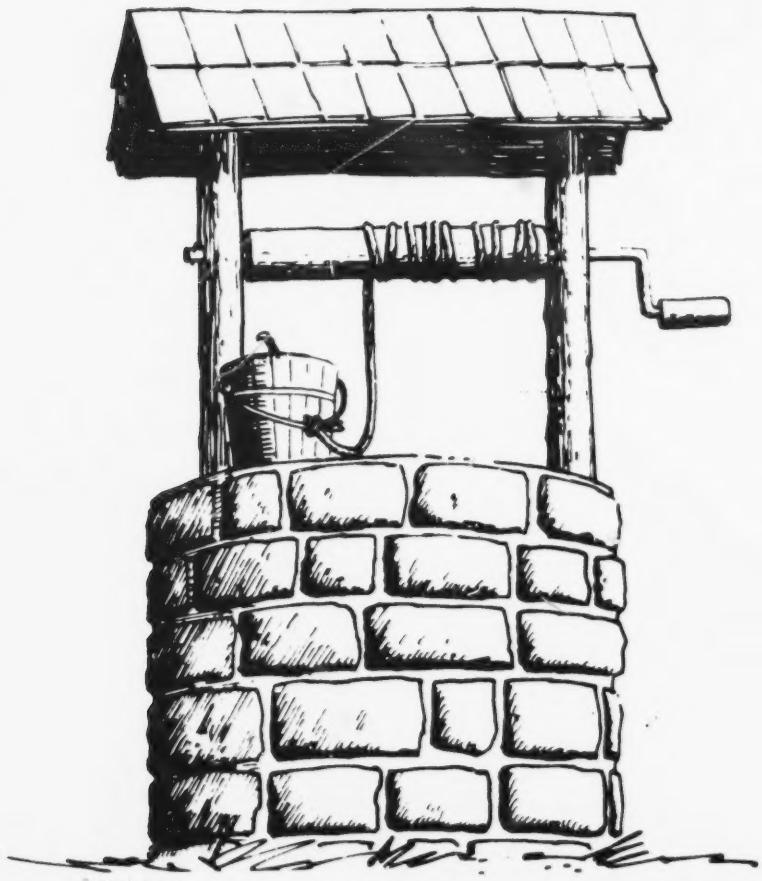
W72-12042

CLEAN WATER
WATER POLLUTION CONTROL RESEARCH SERIES ● 16060 DOE 04/72

PB 211 166

NITRATE IN THE UNSATURATED ZONE UNDER AGRICULTURAL LANDS



Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. Department of Commerce
Springfield VA 22151

U.S. ENVIRONMENTAL PROTECTION AGENCY

45

WATER POLLUTION CONTROL RESEARCH SERIES

The Water Pollution Control Research Series describes the results and progress in the control and abatement of pollution in our Nation's waters. They provide a central source of information on the research, development, and demonstration activities in the water research program of the Environmental Protection Agency, through inhouse research and grants and contracts with Federal, State, and local agencies, research institutions, and industrial organizations.

Inquiries pertaining to Water Pollution Control Research Reports should be directed to the Chief, Publications Branch (Water), Research Information Division, R&M, Environmental Protection Agency, Washington, DC 20460.

NITRATE IN THE UNSATURATED ZONE UNDER AGRICULTURAL LANDS

by

P. F. Pratt
Department of Soil Science and Agricultural Engineering
University of California
Riverside, California 92507

for

Research and Monitoring
ENVIRONMENTAL PROTECTION AGENCY

Project No. 16060DOE
April, 1972

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price 55 cents

EPA Review Notice

This report has been reviewed by the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

W 72-12042

NITRATE IN THE UNSATURATED ZONE UNDER AGRICULTURAL LANDS,

Pratt, P. F.

California University, Riverside, Dept of Soil Science and Agricultural Engineering

EPA 16060DOE 04/72

Environmental Protection Agency, Water Pollution Control Research Series, ~~Project Reports 16060DOE~~, April 1972. 45p, 9 fig, 9 tab, 12 ref.

Factors that have an effect on the nitrate in drainage water under lands used for citrus and row crops in the Santa Ana River basin in Southern California are the difference between N input and N removed by harvested crops, the drainage volume in which the nitrate is dissolved, mineralization of N from the organic pool, and denitrification. The N input minus N removed in harvested crops provides a reasonable estimate of the nitrate that will leach to the groundwater from soils that have open-porous profiles with no layers that restrict water movement and in which there is no net change in the N in the organic pool. The transit times measured for drainage water to move to the groundwater suggests that the effects of agricultural land use in the 1920 to 1940 period are showing in wells in 1971 and that the effects of present practices will not show until about 1990 or 2000. Recommended practices for fertilizer N for citrus are such that when combined with adequate leaching and good yields will put no more than about 20 ppm nitrate into drainage effluents, assuming no denitrification. Very careful management could reduce this estimate to near 10 ppm. Recommended practices for N fertilizer in row crops would put the nitrate concentration between about 20 to 50 ppm, assuming no denitrification. (Knapp-USGS)

*Nitrates, *Water pollution sources, *Return flow, *Fertilizers, *Path of pollutants, Nitrification, Denitrification, Nitrogen, Irrigation practices, California, Leaching, Nitrogen compounds, Nutrients,

*Santa Ana River basin (Calif),

Copy available from GPO Sup Doc EPA 16060 DOE 04/72 $0.55 ; microfiche from NTIS as PB 211 166, $0.95.

~~02F~~ 05B, 03F, 02G

19. Security Class. (Report) | 21. No. of Pages

20. Security Class. (Page) | 22. Price

Send To:
WATER RESOURCES SCIENTIFIC INFORMATION CENTER
U.S. DEPARTMENT OF THE INTERIOR
WASHINGTON, D. C. 20240

G. Knapp, 8/3/72 | U.S. Geol. Survey, Water Res. Div.

ABSTRACT

Six treatments from a fertility trial with citrus, four commercial citrus groves and nine row-crop fields were studied to assess the effect of fertilizer N on the concentrations of NO_3^- in the unsaturated zone between the root zone and the saturated zone. Nitrate-N concentrations of 21 to 70 and 36 to 123 ppm in the water in the unsaturated zone were found for citrus and row crops respectively. The main factors were 1) the difference between N input and crop removal, 2) drainage volume and 3) soil profile characteristics that apparently control denitrification. In soil profiles having no layers that restrict water movement and in which the net change in the amount of N in the organic pool was essentially zero the amount of N input minus crop removal expressed as NO_3^- in the drainage water provided a reasonably reliable estimate of the NO_3^- concentration in the solution of the unsaturated zone. An estimate of transit time for drainage water through the unsaturated zone provided a means of calculating a field N balance.

This report was submitted in fulfillment of Grant No. 16060DOE under the sponsorship of the Office of Research and Monitoring, Environmental Protection Agency.

CONTENTS

Section		Page
I	Conclusions	1
II	Recommendations	3
III	Introduction	5
IV	Approach	7
V	Methods	11
VI	Results	13
VII	Discussion	35
VIII	Acknowledgments	39
IX	References	41
X	Publications and Patents	43
XI	Glossary	45

Preceding page blank

FIGURES

		PAGE
1	RELATIONSHIP BETWEEN NO_3^--N CONCENTRATION AND EXCESS N FOR FOUR DRAINAGE VOLUMES, CALCULATED USING EQUATION [2]	8
2	RELATIONSHIP BETWEEN NO_3^- CONCENTRATION IN THE SATURATION EXTRACT AND DEPTH (0- TO 3-m) AND BETWEEN NO_3^--N CONCENTRATION IN THE SOIL SOLUTION AND DEPTH (3- TO 30-m) FOR TWO TREATMENTS	14
3	RELATIONSHIP BETWEEN Cl^- CONCENTRATION AND DEPTH FOR TWO TREATMENTS. THE TOP PART IS FOR SATURATION EXTRACTS AND THE LOWER PART IS FOR SOIL SOLUTIONS	15
4	RELATIONSHIPS AMONG EXCESS N IN THE SOIL, NO_3^--N IN THE SOIL WATER OF THE UNSATURATED ZONE (3- TO 30-m DEPTH) AND THE LEACHING VOLUME. THE CURVES WERE CALCULATED FROM EQUATION [2], THE NUMBERED POINTS ARE FROM THE FERTILITY TRIAL, AND THE LETTERED POINTS ARE FROM COMMERCIAL GROVES. FOR TREATMENT 21 ONLY THE DATA FOR THE 3- TO 20-m DEPTH WERE USED	19
5	RELATION BETWEEN MEASURED NO_3^--N IN THE SOIL AND THE AMOUNT ESTIMATED BY MULTIPLYING THE AVERAGE EXCESS N PER YEAR TIMES THE TRANSIT TIME IN YEARS PER 30 m	20
6	NITROGEN RECOVERY AND N LOSS BY DENITRIFICATION IN RELATION TO TOTAL N INPUT	22
7	RELATIONSHIP BETWEEN NO_3^--N CONCENTRATION AND DEPTH FOR THREE SITES IN FIELD USED FOR ROW CROPS	28
8	RELATIONSHIP BETWEEN Cl^- CONCENTRATION AND DEPTH FOR THREE SITES IN FIELDS USED FOR ROW CROPS	29
9	RELATIONSHIP BETWEEN EXCESS N AS CALCULATED FROM EQUATION [2] PER TRANSIT TIME AS CALCULATED FROM EQUATION [3], AND THE MEASURED NO_3^--N EXCESS IN THE SOIL FOR THREE BULK DENSITIES. THE CORRELATION COEFFICIENT IS FOR A B.D. OF 1.8. THE NUMBER IDENTIFIES THE SITE	34

TABLES

No.		Page
1	Nitrogen Fertilizer Treatments on the Six Treatments Selected for Deep Soil Sampling in the Long-Term Fertilizer Trial	13
2	Average Concentration of SO_4^{-2}, Cl^- and NO_3^- in the Saturation Extract of the 0- to 2.4-m Depth of Soil	16
3	Average Concentration of NO_3^--N and Cl^- in the Soil Solution, (Field Water Content) of the 3- to 30-m Depth of Soil and the Calculated Leaching Fraction	17
4	Linear Correlation Coefficients and Regression Equations for the Relationships of $SO_4^=$, Cl^-, and NO_3^- Concentrations in the 0- to 2.4-m Depth and the NO_3^--N Content of the Soil Solution of the 3- to 30-m Depth Versus Leaching Fraction	17
5	Data for Transit Time for Water and NO_3^- to Move 30 m and N Balance for the Indicated Transit Time	18
6	Data for Four Commercial Groves Sampled in the Spring of 1970	23
7	Description of the Row-Crop Sites Studied	24,25
8	Data for NO_3^-, Cl^-, EC and Water Content for the 0- to 2.4-m and 3.3- to 15-m Depths of Soils for Nine Row-Crop Sites	27,28
9	Estimates for the Transit Time for Water in the Unsaturated Zone and N Balance for Nine Row-Crop Sites	30,31

SECTION I

CONCLUSIONS

1. Factors that have an effect on the NO_3^- in drainage water under lands used for citrus and row crops in the Santa Ana River Basin in Southern California are

    1) difference between N input and N removed by harvested crops,

    2) drainage volume in which the NO_3^- is dissolved,

    3) mineralization of N from the organic pool, and

    4) denitrification.

2. The N input minus N removed in harvested crops provides a reasonable estimate of the NO_3^- that will leach to the ground water from soils that have open-porous profiles with no layers that restrict water movement and in which there is no net change in the N in the organic pool.

3. Knowledge of the drainage volume, N inputs, crop removal of N and transit time for drainage water to move through the unsaturated zone provides a means of estimating denitrification in the field in soils where the organic N content is constant over the period of time that is considered.

4. The general correlation between soil profile characteristics and denitrification losses, as shown in this report, suggests that a rating of soils in terms of probable denitrification might be useful in the assessment of the effects of agriculture on ground water quality.

5. The transit times measured for drainage water to move to the ground water suggests that the effects of agricultural land use in the 1920 to 1940 period are showing in wells in 1971 and that the effects of present practices will not show until about 1990 or 2000.

6. Recommended practices for fertilizer N for citrus are such that when combined with adequate leaching and good yields will put no more than about 20 ppm NO_3^--N into drainage effluents, assuming no denitrification. Very careful management could reduce this estimate to near 10 ppm.

7. Recommended practices for N fertilizer in row crops would put the NO_3^--N concentration between about 20 to 50 ppm, assuming no denitrification.

SECTION II

RECOMMENDATIONS

An intensive educational program needs to be developed to show farm managers the effects of the use of excess N on NO_3^- in ground waters, to encourage them to use no more N than is recommended by the Agricultural Experiment Stations and the Agricultural Extension Services and to use diagnostic techniques not only to avoid deficiencies of N in crops but also to avoid excesses of NO_3^- in drainage waters.

Research along the following lines should be encouraged:

1. The development of denitrification ratings for soil series to help delineate where NO_3^- in drainage waters is a serious problem and where it might be ignored because of effective denitrification.

2. Development and assessment of costs of fertilizer materials, and methods of application that increase the efficiency of fertilizer N use.

3. Feasibility studies on the interception of drainage waters before they become mixed with ground waters and the recycling and disposal of such drainage waters to suitable sumps.

4. Socio-economic studies aimed at the conflict between fertilization for maximum yield of crops and restriction on fertilizer use for maximum quality of drainage waters.

Preceding page blank

SECTION III

INTRODUCTION

Until recently the main reason for measuring the concentration of nitrate (NO_3^-) in the water in the soil material below the effective rooting depth of crop plants was to evaluate the loss of NO_3^- to the crop and estimate the loss of production or a need for more fertilizer N to adjust for the losses. In the last few years, with a tremendous increase in the concern for NO_3^- in surface and ground waters, the emphasis has changed to the study of NO_3^- leaching because of the potential pollution of waters.

A great deal of information is available on nitrogen (N) behavior in soils and the NO_3^- leaching from the plant-soil system in relation to climate and the nature of the soil and crop. Thomas (12) and Stewart (10) have reviewed some of the more important factors. In both of these reviews, the authors strongly emphasized the importance of the rainfall or quantity of drainage water as a factor in leaching of NO_3^-. Nelson (7) discussed the research techniques and approaches needed to resolve some of the unanswered questions on nutrient losses from the soil-plant system. He strongly emphasized the need for assessing NO_3^- losses to ground waters using small confined watersheds, but he also stated that deep soil profile samples can lead to useful information. Stout and Burau (11) have demonstrated the usefulness of deep soil profile samples to determine the NO_3^- concentration in the unsaturated zone.

In irrigated areas of Southern California, with its short rainy season which comes during the winter months and a long dry season requiring intensive irrigation for successful crop production, a number of studies of NO_3^- losses by leaching have been conducted. Pratt and Chapman (8) found small leaching losses of NO_3^- in a 20-year lysimeter study in which leaching was accomplished only during the years of above average winter rainfall. Bingham, et al., (2) found considerable NO_3^- removed in drainage waters of a small watershed in which the leaching fraction was approximately 50 per cent of the irrigation water used.

The present investigation was undertaken to determine the potential contribution of fertilizer N use on citrus and row crops to the NO_3^- in ground waters in the Santa Ana River Basin of Southern California where a deep unsaturated zone exists between the soil profile or crop-root zone and the water table or saturated zone. Specifically, the objectives were 1) to relate NO_3^- concentrations in the unsaturated zone to N inputs, N removal by harvested crops and the volume of drainage water, 2) to obtain some estimates of transit times for drainage water through the unsaturated zone, 3) to estimate denitrification losses on a field basis and 4) to assess the probable effects of present fertilizer N recommendations on NO_3^- in ground waters.

Preceding page blank

The main field used for this study was a long-term fertilizer trial with Washington navel oranges. The trees were planted in 1917, but differential treatments were started in 1927 when 43 treatments were imposed. The main treatments consisted of various rates and sources of N fertilizers. The treatments were discontinued in 1962 after which uniform N treatments were used on all plots. Six treatments that were thought to have had a long-term effect on leaching fractions were sampled to the 30-m depth in June, 1969. In addition, four commercial citrus groves were sampled to the 15-m depth or to the top of the water table in June of 1970 and nine row-crop fields were sampled to the 15-m depth in the Winter of 1971.

SECTION IV

APPROACH

In the analysis of the data the assumptions were that 1) the pool of organic N in the soil was constant from year to year so that the net mineralization or immobilization was zero; 2) the rate of movement of NO_3^-, below the zone of root influence, was the same as the movement of water; and 3) the amount of N denitrified was equal to the total N input minus the sum of removal in the fruit plus that found in the soil. All three assumptions seem to be justified. In the climate of Riverside, moderate additions of organic materials add little to the permanent or semi-permanent organic pool because of rapid mineralization. The second assumption is justified for steady-state or near steady-state conditions but would not be justified in cases of large and abrupt changes in the NO_3^- concentration of the water leaving the root zone.

The volume of the drainage water was calculated from the equation

$$D = \frac{\overline{LF}\ \overline{ET}}{1-\overline{LF}} \qquad [1]$$

which is derived from the definition that the leaching fraction is equal to the drainage volume divided by the sum of the evapotranspiration plus the drainage volume, where D is the volume of drainage expressed in surface cm/year, $\overline{LF}$ is the leaching fraction, and $\overline{ET}$ is the evapotranspiration in surface cm/year. In all cases with citrus, the average $\overline{ET}$ demand during the irrigation season was assumed to be 60 surface cm/year. In row-crop fields, D was calculated as the product of the amount of water used and the leaching fraction.

The amount of excess N available for leaching was calculated from the equation

$$\text{Excess N} = \frac{DNO_3^-}{10} \qquad [2]$$

where excess N is expressed in kg/ha per year, D is the drainage volume in surface cm/year, and the NO_3^- is ppm NO_3^--N in the soil water below the zone of root influence. The units for the constant are mg cm ha kg^{-1} $liter^{-1}$. The relationship between NO_3^--N concentration and excess N available for leaching as NO_3^- for four drainage volumes is presented in Fig. 1.

The transit time for water in the unsaturated zone below the root zone was calculated as

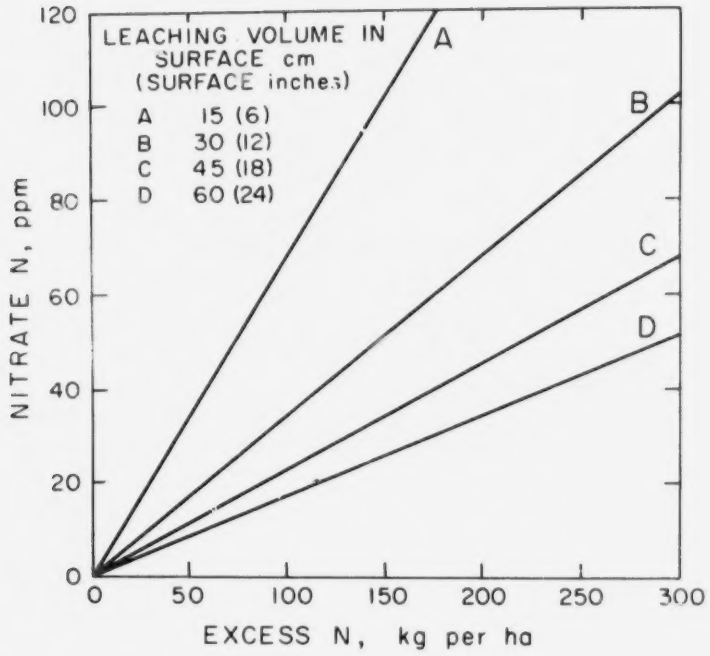


Figure 1. Relationship between NO_3^--N concentration and excess N for four drainage volumes, calculated using equation [2].

$$T = \frac{S\theta}{D} \qquad [3]$$

where T is transit time in years, S is the soil depth in cm, θ is the volumetric water content, and D is the volume of drainage water in surface cm/year. The volumetric water content was calculated as the gravimetric water content times the bulk density, which was 1.8 in the long-term fertilizer trial and was assumed to be the same in the four commercial groves. Equation [3] assumes a complete displacement of water in the soil profile.

The leaching volume, defined as the water that moved past the effective rooting zone of the crops and expressed as a fraction of the irrigation water used, was calculated as a ratio of the Cl^- concentration in the irrigation water to that in the drainage water - i.e., the solution in the unsaturated zone - and is equal to the volume ratio of drainage water to irrigation water. This equality comes from a consideration of simple concentration effects assuming no precipitation or dissolution of Cl^- salts, negligible Cl^- removal in harvested crops and no Cl^- additions in fertilizers. The soils studied have no known mechanism for precipitation or dissolution of Cl^- salts, and most crops remove only relatively small amounts of Cl^-. The mineral fertilizers used contained no important amounts of Cl^- salts, and the Cl^- added in animal manures was relatively small compared to the amount in the irrigation water.

SECTION V

METHODS

Soil samples were taken with a power-driven bucket auger at 30-cm intervals to the 3-m depth inclusive and at 1.5-m intervals below the 3-m depth. Samples were taken to the drying shed in air-tight containers where they were weighed, air dried and weighed again. The loss in weight was used to calculate the water content of the field sample. Air-dried samples were made to a saturated paste by adding distilled water, and saturation extracts were obtained by suction. Extracts were analyzed for NO_3^- and Cl^- and in some cases for $SO_4^=$. In the long-term fertility trial, three holes were drilled per plot and two plots were sampled per treatment. In the commercial citrus groves and in the row-crop fields three holes were drilled per site.

The data reported for the 0- to 3-m depths are in meq/liter in the saturation extracts. The variations in field water content within this soil depth were considered to be so great, because of cyclic changes with irrigation, that conversion to the soil solution basis was considered meaningless. Below the 3-m depth the data were converted from concentrations in the saturation extract to concentrations in the soil solution. The cyclic changes in water content with irrigation and removal by evapotranspiration are limited to the soil volume above the 3-m depth, so that below this the water content is considered to be that at which water is moving to the water table.

Preceding page blank

SECTION VI

RESULTS

Citrus

A description of the treatments selected from the long-term fertility trial with citrus is presented in Table 1. The soil is a Greenfield

Table 1 - Nitrogen fertilizer treatments on the six treatments selected for deep soil sampling in the long-term fertilizer trial

Treatment No.	Fertilizer nitrogen treatments			
	1963 to 1969 inclusive		Prior to 1963	
	Annual rate	Source*	Annual rate	Source*
	kg/ha		kg/ha	
1	168	NH_4NO_3	56	---
6	168	NH_4NO_3	56	---
21	168	NH_4NO_3	392	$Ca(NO_3)_2$
23	168	NH_4NO_3	616	$Ca(NO_3)_2$
26	168	NH_4NO_3	392	$NaNO_3$
30	168	NH_4NO_3	220	Steer Manure

*The average amount of N added as NO_3^--N in the irrigation water (56 kg/ha/yr) is included in these rates.

sandy loam which has no layers that restrict water movement within the 0- to 3-m depth. Below the 3-m depth the soil material consists of interlayers of fine to coarse sands with sandy loams to loams. The only layer with an appreciable organic matter content is the surface 30 cm.

Figures 2 and 3 present concentration-depth relationships for NO_3^- and Cl^- respectively (see pages 14 and 15).

Data for the 0- to 3-m depth are given for saturation extracts because of the transitory nature of the field water content of this depth; whereas, for the 3- to 30-m depth the water content was considered sufficiently constant that the conversion of the data to the field

Preceding page blank

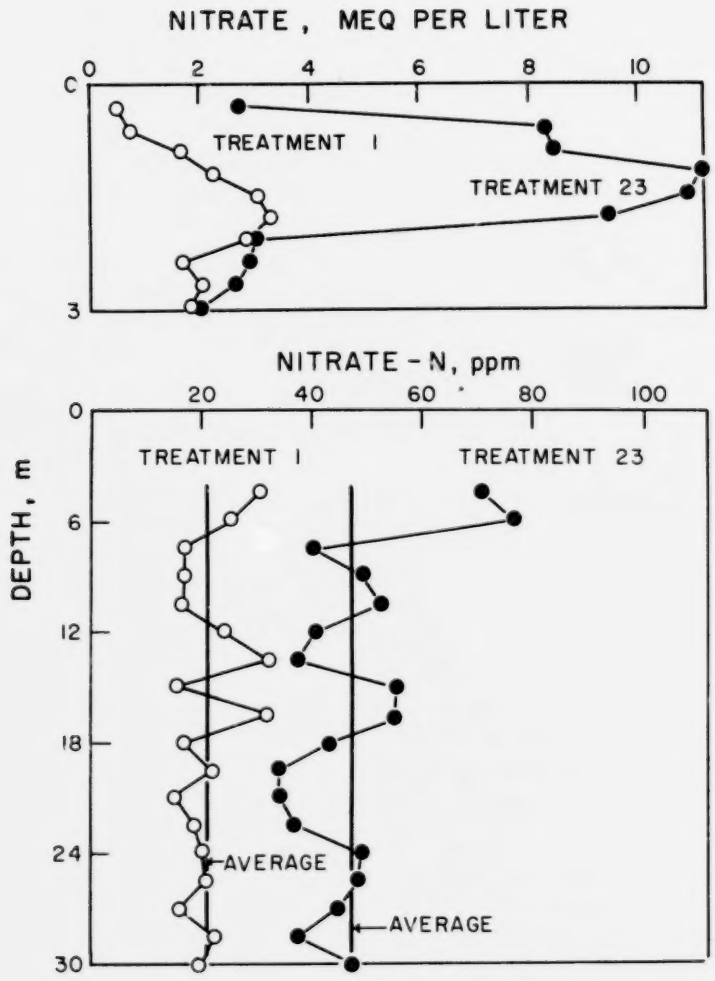


Figure 2. Relationship between NO_3^- concentration in the saturation extract and depth (0- to 3-m) and between NO_3^--N concentration in the soil solution and depth (3- to 30-m) for two treatments.

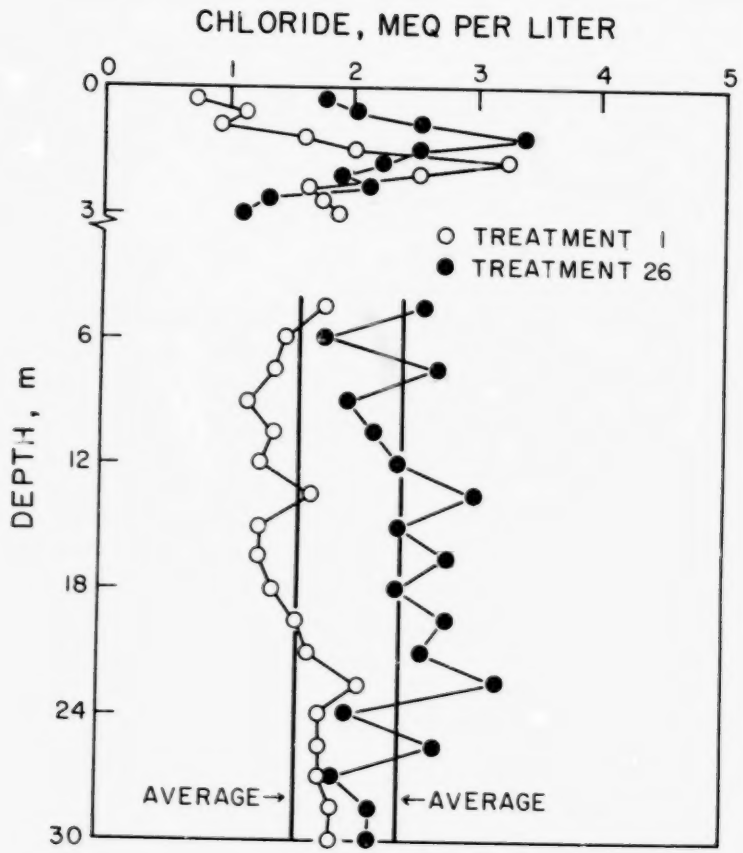


Figure 3. Relationship between Cl^- concentration and depth for two treatments. The top part is for saturation extracts and the lower part is for soil solutions.

water content was justified. The data in these figures are typical of the variabilities found in all treatments. The data represent the averages of six sampling sites for a stated depth of soil.

Table 2 presents data on the average SO_4^{2-}, Cl^- and NO_3^- concentrations in the saturation extracts of the 0- to 2.4-m depth of soil for the long-term fertility trial.

Table 2 - Average concentration of SO_4^{2-}, Cl^-, and NO_3^- in the saturation extract of the 0- to 2.4-m depth of soil

Treatment No.	Average Concentration		
	Sulfate	Chloride	Nitrate
	----------meq per liter----------		
1	3.4	1.4	2.0
6	4.2	1.8	3.3
21	3.9	1.5	2.9
23	8.8	2.1	7.1
26	11.4	2.5	8.1
30	6.3	1.8	3.0

Table 3 presents data on the average NO_3^--N and Cl^- concentrations in the soil water, i.e., soil solution for the 3- to 30-m depth of soil and the leaching fraction. Linear correlation coefficients and regression equations for NO_3^- and SO_4^{2-} in the saturation extract of the 0- to 2.4-m depth, and NO_3^--N content of the soil solution in the 3- to 30-m depth versus leaching fraction are presented in Table 4.

Table 3 - Average concentration of NO_3^--N and Cl^- in the soil solution (field water content) of the 3- to 30-m depth of soil and the calculated leaching fraction

Treatment No.	Nitrate N	Chloride	Leaching Fraction	Water Content
	-----meq/liter---------			% by weight
1	1.50	1.62	0.40	9.0
6	1.57	1.81	0.36	9.4
21	1.50(3.21)*	1.58	0.41	9.0
23	3.36	1.91	0.34	7.9
26	4.57	2.51	0.26	9.1
30	1.79	1.81	0.36	8.9

*Average was 21 ppm to the 20-m depth inclusive and 45 ppm from the 21- to 30-m depth.

Table 4 - Linear correlation coefficients and regression equations for the relationships of $SO_4^=$, Cl^-, and NO_3^- concentrations in the 0- to 2.4-m depth and the NO_3^--N content of the soil solution of the 3- to 30-m depth versus leaching fraction

Variable	Correlation Coefficient	Regression Equation
Saturation Extract		
Sulfate	-0.93**	Y = 26.0 - 55.4x
Chloride	-0.97**	Y = 4.46 - 7.35x
Nitrate	-0.88*	Y = 19.1 - 41.5x
Soil Solution		
Nitrate - N†	-0.92**	Y = 143.4 - 310.1x

*Significant at the 0.05 probability level
**Significant at the 0.01 probability level
† In treatment 21 the NO_3^--N concentration in the 3- to 20-m depth was used.

The relationships among NO_3^--N in the water of the 3- to 30-m depth, excess N in the soil, and the volume of the drainage water are presented in Figure 4. Excluding the lower depths of treatment 21, calculated excess N varied from 39 to 145 kg/ha per year. From this figure one can see that without data for the drainage volume the NO_3^- concentration in the soil water does not provide an index to the amount of NO_3^- that was available for leaching. Evidently treatments 23 and 26 reflect the higher rates of N application used prior to 1963 more than treatments 1, 6, 30 and 21.

For some unexplained reason, treatment 21 reflects the change in treatment of 1963, with the lower depth representing the 392 kg/ha rate and the upper depth representing the 168 kg/ha rate. In all other treatments the NO_3^--N concentration showed no changes with depth that would represent the change in fertilizer rates in 1963. The lower depth in treatment 21 showed an excess N of 187 kg/ha per year whereas the upper layer showed an excess N of 87 kg/ha per year. Comparisons against N added (Table 1) and removal in fruit (Table 5) show denitrification rates of 34 and 158 kg/ha per year, respectively for input rates of 168 and 392 kg/ha per year.

Table 5 - Data for transit time for water and NO_3^- to move 30 m and N balance for the indicated transit time

Treatment No.	Transit Time for 30 m Years	Nitrogen, kg/ha for transit time: Added	In soil 0- to 30-m Depth*	Removed in Fruit	Loss from System** Entire Period	Yearly	% Loss
1	12.0	1,460	1,220	470	-230	-19.0	-15.8
6	14.2	1,580	1,390	540	-350	-24.6	-22.2
21	11.5	2,940	1,670	480	790	68.7	26.9
23	15.5	6,410	2,990	640	2,780	179.3	43.4
26	22.7	7,330	3,890	790	2,650	116.7	36.2
30	14.2	2,760	1,510	650	600	42.2	21.7

*Measured at the end of the period.
**If value is negative, it is an unaccounted-for increase in input, if positive it is an assumed denitrification loss.

The soils in the commercial groves were mapped as Arlington loam for sites A and C, Greenfield sandy loam for site B, and Hanford sandy loam for site D. A more detailed look at the soil profiles on the sampling sites showed that sites B and C had sandy loam materials to the 3-m depth with no textural discontinuities and no pans of any kind. Sites A and D both had clayey horizon at the 45- to 100-cm depth with coarse to fine sands at the 100-cm depth. This textural

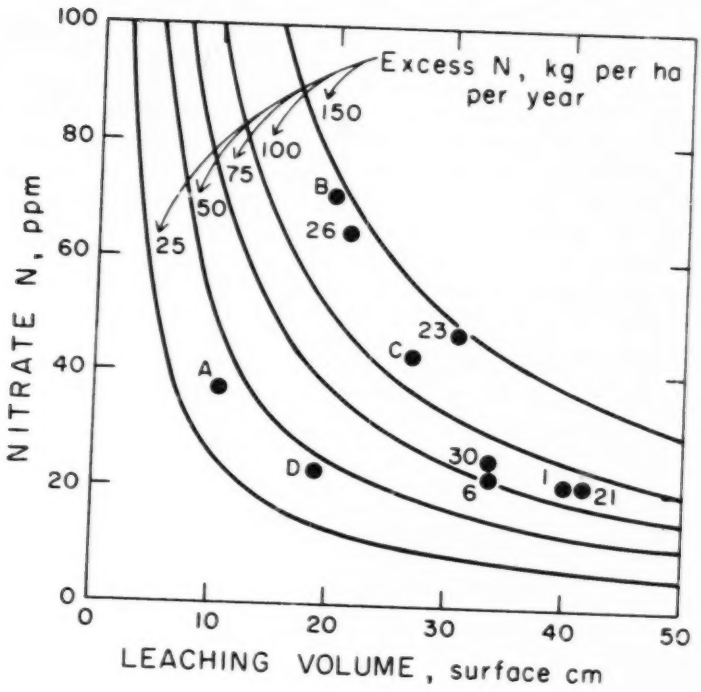


Figure 4. Relationships among excess N in the soil, NO_3^--N in the soil water of the unsaturated zone (3- to 30-m depth) and the leaching volume. The curves were calculated from equation [2], the numbered points are from the fertility trial, and the lettered points are from commercial groves. For treatment 21 only the data for the 3- to 20-m depth were used.

discontinuity is sufficient to create water-saturated soil during irrigation and would be conducive to denitrification; whereas, in the other two soils, a saturated soil during irrigation would not be expected. Because the rates of N applications varied only slightly (154 to 186 kg/ha per year), the possible profile effect on denitrification would appear to explain the low NO_3^--N concentration in sites A and D in comparison to those in sites B and C.

The relation between measured NO_3^--N in the soil and the amount estimated by multiplying the estimated excess N per year times the transit time in years per 30 m is presented in Fig. 5. Because the excess N per year is based on the average (for treatment 21 the weighted average) NO_3^- in the 3- to 30-m depth and the transit time is for the 0- to 30-m depth, we would expect the estimated value to be greater than the measured value in the 3- to 30-m depth (line C). However, when the NO_3^--N in the 3- to 30-m depth is projected to 30 m, a near perfect agreement between measured and estimated was obtained (line B). The difference between lines A and B represents the accumulation of the NO_3^- in the surface 3 m in comparison to the concentration below 3 m.

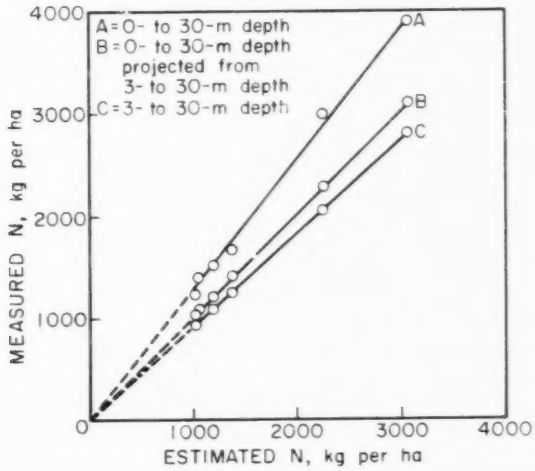


Figure 5. Relation between measured NO_3^--N in the soil and the amount estimated by multiplying the average excess N per year times the transit time in years per 30 m.

This accumulation of NO_3^- in the zone of influence of the root system of the trees is thought to be the result of a combination of factors including 1) recycling of N by the trees, 2) the heterogenous nature of the salt distribution with the use of permanent furrows for irrigation, and 3) the continuous movement of water down with each irrigation and up during periods of extraction by trees between irrigations. During irrigation, water moves down rapidly through large pores with poor efficiency of salt movement, but the water that moves back up to the root zone moves through smaller pores with a larger efficiency of salt transport. Also, irrigation with permanent furrows moves salt into furrow ridges and this salt is moved out slowly by infrequent winter rains. This combination of salt cycling within the zone of root influence and the salt entrapment in permanent furrows is thought to be the mechanism by which the NO_3^- that had accumulated in soils prior to 1963 was carried over to the 1969 sampling date in treatments 23, 26 and 30.

Data for the calculated transit times and for N balances for the calculated transit times for the treatments in the long-term fertilizer trial are presented in Table 5, and data for calculated denitrification are presented graphically in Fig. 6. Treatments 1 and 6 showed small gains which could be within errors of estimate. In treatments 21 through 30 fairly large amounts of N were lost by denitrification. The high correlation between recovery in soil and fruit and the total N input would suggest that the losses are real and that up to 43% of the total N input was denitrified.

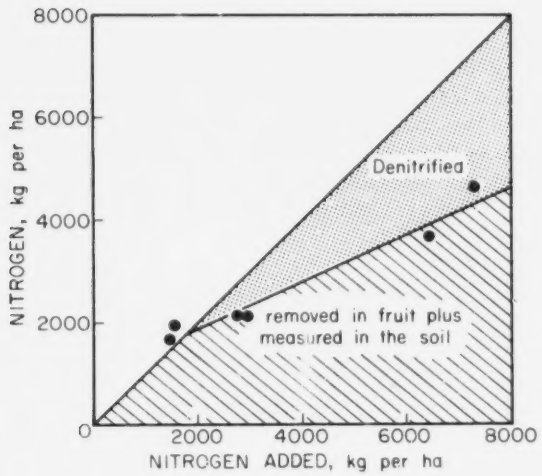


Figure 6. Nitrogen recovery and N loss by denitrification in relation to total N input.

In treatment 21, which had a discontinuity in NO_3^- concentration at the 20-m depth with the upper part of the profile reflecting the 168 kg N rate and the lower part reflecting the 392 kg rate, the calculated transit time for 20 m is 7.7 years. The agreement with the period between the start of the lower rate and sampling date (7 years) is excellent. The difference in behavior between treatment 21 and treat-

ments 32, 26 and 30 is not readily explained by any data or management history.

Data for the four commercial groves sampled in the spring of 1970 are presented in Table 6. The N balance calculated for a 10-year period is a projection of the data to put all four sites on the same basis. The N balance data also must be considered as rough estimates primarily because the removal by fruit is an assumed value of 40 kg/ha per year. However, in this N balance data the two soil profiles that had clayey horizons overlying the sands had an average of 52 per cent loss by denitrification, and the two soil profiles with no textural discontinuities or pans showed an average net unaccounted-for gain of 5 per cent.

Table 6 - Data for four commercial groves sampled in the spring of 1970

Data description	Commercial groves sites			
	A	B	C	D
Leaching fraction	0.15	0.25	0.31	0.24
Leaching volume, surface cm	10.6	20.0	27.0	18.9
Water content, % by weight	9.70	7.36	9.61	21.4
Water content, % by volume	17.5	13.2	17.3	31.1
Sampling depth, m	13.5	15.0	7.5	13.5
Transit time, years	22.0	10.0	4.8	22.0
Transit time, years per 30 m	49	20	19	49
Nitrogen Balance for 1960-1970 Period				
Added, kg/ha	1,540	1,540	1,670	1,880
Fruit removal, kg/ha	400	400	400	400
Excess in soil, kg/ha	390	1,420	1,160	430
Loss, kg/ha*	750	-280	110	1,050
Loss, %*	49	-18	7	56

*If value is negative, it is an unaccounted-for increase in input, if positive, it is assumed denitrification loss.

Row Crops

The soil type and subgroup, a brief profile description, the rate and sources of fertilizer N and the cropping history for each of nine sites are presented in Table 7. All sites were irrigated by furrow irrigation except winter barley crops which were irrigated with sprinkler systems. The NO_3^- added in the irrigation water was not included in the data in Table 7 but was included for the N input data in Table 9.

Table 7 - Description of the row-crop sites studied

Site No.	Soil Description	Profile Description*	N rate (kg/ha/yr)+ and source	Croppings
1	San Emigdio sandy loam (pH 8.0); Typic Xerorthent	Open-porous well drained.	350 as $(NH_4)_2SO_4$ for 5 yrs.	Strawberries & barley on alternate years. The strawberry crop was mulched with a plastic film each season to increase soil temperature and conserve soil moisture.
2	Sorrento clay loam (pH 7.5); Calcic Haploxeroll	Stratified with silts & sandy loams.	1,350 as chicken manure (625 kg N per year), $(NH_4)_2SO_4$, NH_4NO_3, and cyanamid for 5 years.	Celery during winter & sweet corn during summer.
3	Buchenau loam (pH 7.9); Typic Durixeralf	Stratified, presence of caliche at the 1.5-m depth.†	470 as barnyard and chicken manures (1960-68), $Ca(NO_3)_2$ solutions, and mixed fertilizers for 11 years.	Cabbage, green onions, celery, and romaine lettuce in rotation.
4	Arlington sandy loam (pH 7.8); Haplic Durixeralf	Hardpan about 40 cm thick at the 0.8-m depth.	163 mostly as chicken manure and a small amount of mixed fertilizers applied during seeding for 6 years.	Sugar beets and grain crops in rotation.

Table 7 - Continued

Site No.	Soil Description	Profile Description*	N rate (kg/ha/yr)+ and source	Croppings
5	Hanford loamy sand (pH 7.7); Typic Xerorthent	Open-porous well-drained.	Same as site 4.	Grain crops with sugar beets in 1969-70 only.
6	San Emigdio fine loam (pH 7.3); Typic Xerorthent	Stratified; presence of claypan about 30 cm thick at the 0.9-m depth	370 mostly as chicken manure & a small amount of mixed fertilizers for 4 years.	One year of watermelons & three consecutive years of carrots.
7	Hanford sandy loam (pH 7.3); Typic Xerorthent	Hardpan about 45 cm thick at the 0.8- to 1.0-m depth.	224 as chicken manure, aqua NH_3, and $(NH_4)_2SO_4$ for 11 years.	Potatoes for one year followed by three consecutive years of cereal crops.
8	Grangeville fine sandy loam (pH 7.7); Aquic Haploxeroll	Stratified; slight mottling at about the 1-m depth.	480 as barnyard manure (1959-63), $(NH_4)_2SO_4$, and mixed fertilizers for 11 years.	Potatoes in 1964,'65 and '69 & sweet corn.
9	Delhi loamy fine sand (pH 7.4); Typic Xeropsamment (Taxadjunct)	Open-porous, well drained	320 mostly as barnyard manure & a small amount of $(NH_4)_2SO_4$ for 11 years.	Eight consecutive years of alfalfa & later 3 years of potato-barley.

*Surface 2 m with emphasis on the presence of restricting layer.
+Annual average for the indicated period.
‡For sites 3, 6 and 8 the profiles were stratified with silts, very fine sands, and sandy loams. The caliche in site 3 had not accumulated in a solid layer, was about 1 to 2 cm in diameter, and scattered.

Data for NO_3^- and Cl^- concentrations, electrical conductivity, and water content for two depths are presented in Table 8. The values are means of three holes for each site. The NO_3^- and Cl^- are expressed as ppm and meq/liter, respectively, in the saturation extracts for the 0- to 2.4-m depth since at this depth water contents fluctuate with irrigation practice and evapotranspiration by the crop and in the soil solution for the 3.3- to 15-m depths where the water is considered unavailable to crops and would be leached to the ground water. The average NO_3^--N content for the 3.3- to 15-m depths ranged from 36.0 to 122.6 ppm. There was a positive correlation ($r = 0.70$, $n = 9$), significant at the 5 per cent level, between the N input per year and the average concentration of NO_3^--N in the soil solution at the 3.3- to 15-m depths. The sites having the highest NO_3^--N concentrations of 84.9, 119.2, and 122.6 ppm had average application rates of 470, 1,350, and 480 kg N/ha per year, respectively, whereas the sites having the lowest NO_3^--N concentrations of 36.0, 53.4, and 56.2 ppm had application rates of 224, 350, and 163 kg N/ha per year respectively.

The ground water at the 12-m depth (top of the saturated zone) in site 3 had a NO_3^--N concentration of 140 ppm and that for site 8 at the 14-m depth had 93 ppm NO_3^--N. In contrast, the irrigation waters pumped from wells approximately 26 m deep for site 3 and 45 m deep for site 8 had only 19 and 7 ppm NO_3^--N respectively. This pattern of wide divergence in NO_3^- content at different aquifer depths was similar to that reported for dairy farming areas, where NO_3^- concentrations in the ground waters at shallow depths were considerably higher than in waters pumped from deeper depths (1). This distribution of NO_3^- concentrations as a function of depth within the aquifer (saturated zone) indicates that the recycling of high NO_3^- ground water from shallow depths as a source of N for plants might be feasible. The limitation, however, might be the salt levels that are positively correlated with the NO_3^- concentrations.

Data for the NO_3^- and Cl^- concentrations of three selected sites are presented graphically in Figures 7 and 8, respectively. Site 1 represented an area which received a medium rate of fertilizer N but had a relatively high drainage volume and, thus, should have relatively low NO_3^- and Cl^- concentrations. Site 2, which had high N input rates, had high NO_3^- concentrations in spite of a high drainage volume. Site 7 had low rates of N and also a low drainage volume.

Data for transit time for water in the unsaturated zone and for calculated N balance are shown in Table 9. The N balance data are for periods when records were available for fertilization, irrigation, and crop yields for each site studied. The data cannot be extended to cover a period equal to the transit time for water for a given depth or to compare all the sites on the same time basis because records were not available for all sites for these periods. Thus,

Table 8 - Data for NO_3^-, Cl^-, EC and water content for the 0- to 2.4-m and 3.3- to 15-m depths of soils for nine row-crop sites.

Site No.	NO_3^--N, ppm*		Cl^-, meq/liter*		EC, mmho/cm+		Soil water % ny wt	
	0- to 2.4 m	3.3- to 15 m	0- to 2.4 m	3.3- to 15 m	0- to 2.4 m	3.3- to 15 m	0- to 2.4 m	3.3- to 15 m
1	15.5^{b}†	53.4^{bc}	0.59^{d}	1.37^{c}	0.47^{d}	0.53^{c}	8.5	9.9
2	52.5^{b}	119.2^{a}	2.86^{cd}	5.18^{c}	1.40^{bcd}	1.37^{ab}	17.9	16.9
3	24.9^{b}	84.9^{b}	4.52^{c}	9.15^{bc}	1.20^{cd}	1.27^{bc}	16.4	18.0
4	27.9^{b}	60.0^{bc}	10.33^{b}	36.08^{a}	1.70^{abc}	2.01^{a}	7.8	9.7
5	18.9^{b}	56.2^{bc}	16.72^{a}	10.96^{bc}	2.45^{a}	0.83^{bc}	6.8	15.5
6	48.5^{b}	61.7^{bc}	5.92^{c}	21.24^{b}	2.13^{ab}	1.17^{bc}	11.4	9.0
7	21.9^{b}	36.0^{c}	5.98^{c}	12.56^{bc}	2.28^{ab}	0.87^{bc}	7.1	10.2
8	122.7^{b}	122.6^{a}	0.97^{d}	2.16^{c}	1.27^{bcd}	1.03^{bc}	12.6	22.8
9	25.7^{b}	76.5^{b}	2.69^{cd}	1.53^{c}	0.98^{cd}	0.58^{c}	10.2	12.3

*Nitrate and Cl^- concentrations in saturation extracts at 0- to 2.4-m depths and in soil water at 3.3- to 15-m depths.

+In saturation extracts at 25 C.

†At the 5% level, values sharing the same letter are statistically alike.

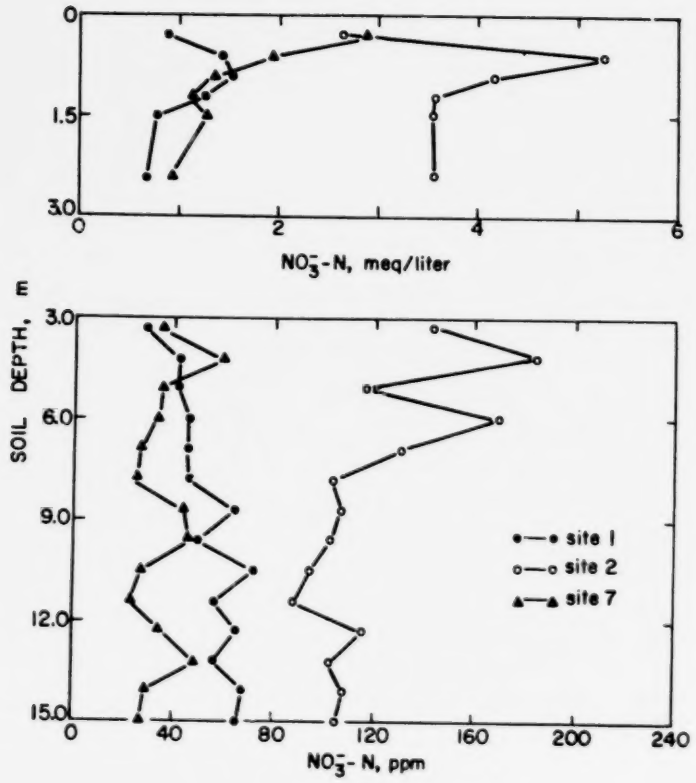


Figure 7. Relationship between NO_3^--N concentration and depth for three sites in field used for row crops.

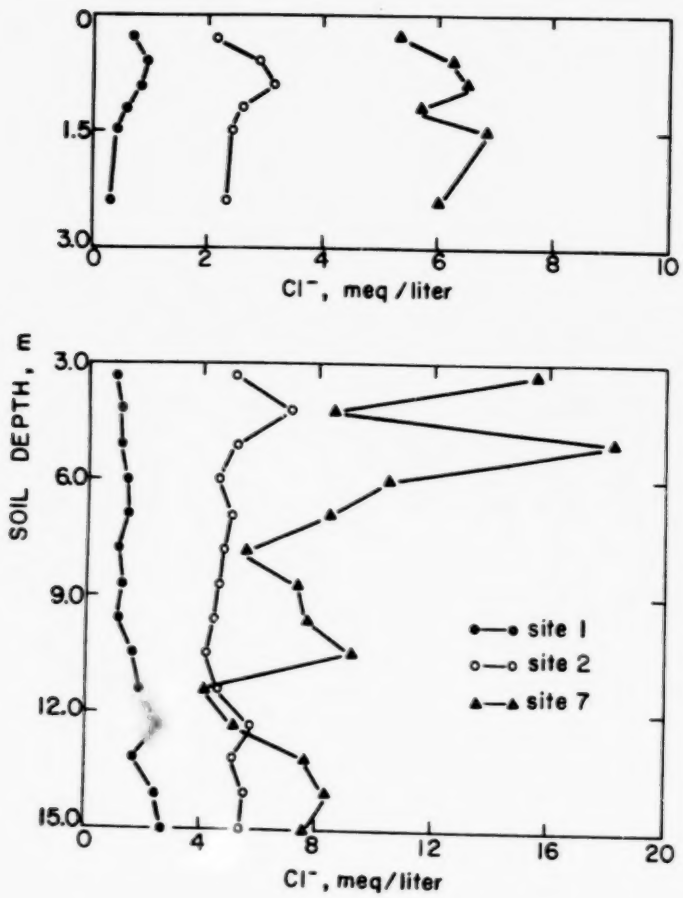


Figure 8. Relationship between Cl^- concentration and depth for three sites in fields used for row crops.

Table 9 - Estimates for the transit time for water in the unsaturated zone and N balance for nine row-crop sites.

Description	Site No. 1	2	3	4	5	6	7	8	9
Leaching fraction	0.65	0.42	0.46	0.15	0.46	0.16	0.17	0.38	0.29
Leaching volume surface cm	58	76	66	14	39	12	13	26	31
Water content % by volume	17.1*	31.0	31.3	16.4	23.2	17.6	16.7	35.3	21.1
Sampling depth, m	15	15	12	15	15	15	15	14	15
Transit time for 15 m, years	4.4*	6.1	7.1	17.6	8.9	22.0	19.3	20.5	10.2
	Nitrogen Balance for the Indicated Period								
Period, years	5	5	11	6	6	4	11	11	11
Input, kg/ha**	2185	7625	8140	1260	1290	1920	3960	5830	4785
Crop removal, kg/ha	335	1925	2485	890	910	580	1330	1205	2080

Table 9 - Continued

Period, years	5	5	11	6	6	4	11	11	11
Excess in soil, kg/ha+	1550	4350	5324	510	1320	265	572	3487	2610
Loss, kg/ha	300	1350	331	-140	-940	1075	2058	1138	95
Loss, %+	13.7	17.7	4.1	-11.1	-72.9	56.0	52.0	19.5	2.0

*Values for water content and transit time are for a bulk density of 1.8.

**Input data include N added in irrigation waters.

+Calculated at the end of the period from equation 2.

†Negative values were unaccounted-for increases in input and positive values were presumably caused by denitrification.

the N balance data for site 3 are for transit time for a 30-m depth, whereas the data for site 6 were based on a transit time for a 3-m depth. However, for sites 1, 2, 5 and 9, the indicated periods were close to the values for transit time for 15 m. The values for the N loss were calculated as equivalent to the total N input minus the sum of N removed by crops and excess N in the soil. The amount of N removed by crops was calculated as the product of harvested crops for the indicated period and the N concentration in the crops. The values for NO_3^- used for the calculation of excess N (equation 2) were the average in the soil solution at the 3.3- to 15-m depths. The amount of N loss was assumed to be a result of denitrification although some of this apparent N loss could have resulted from N incorporation into the organic N pool in the soil.

The apparent N losses ranged from -72.9 to 56.0 per cent of the total N input during the test periods. However, the sites fit into essentially four categories: sites 3 and 9 with near zero loss; sites 1, 2 and 8 with losses of 13.7 to 19.5 per cent; sites 6 and 7 with 56.0 and 52.0 per cent losses, respectively; and sites 4 and 5 with unaccounted-for inputs. Site 3 had some degree of stratification but had no restricting layer in the 0- to 2-m depth. Site 9 had an open-porous soil profile, and like site 3, had minimum possibilities for denitrification to occur. Sites 1, 2 and 8 also had reasonably open-porous profiles, except that sites 2 and 8 had relatively more stratification, and evidently some denitrification may have occurred. Actually, in these types of field studies, 13 to 20 per cent unaccounted-for losses are not high and one might consider the use of equation [2], in which excess N is equal to inputs minus crop removal, to give a valid estimate for NO_3^- concentrations in the drainage water in these three sites. Sites 6 and 7 had profiles conducive to denitrification. In both cases, soil layers that would restrict the rate of movement of water existed within the usual soil profile (0- to 2-m depth). In sites 4 and 5, which had been used for disposal of steer manure prior to the start of row cropping in 1964, mineralization from the organic N pool apparently occurred. Site 4 (Arlington) had the profile most likely to have produced denitrification, whereas site 5 (Hanford) had an open-porous profile. Thus, if both sites had about the same mineralization rates, the much lower apparent unaccounted-for inputs in site 4 could have been caused by a much greater loss by denitrification.

Calculations for site 9, which had 8 consecutive years of alfalfa and a N balance of 2 per cent, did not include an estimate of N fixation by symbiosis.

If some N were taken from the air by this process. it was balanced by losses or by errors of estimate in the factors that went into the calculation of the N balance. Actually, the inefficiency of N fixation by symbiosis in alfalfa when the soil is well supplied with

available N is well known. In this case with an average input of 435 kg N per ha per year, the fixation of N by symbiosis is likely to have been negligible.

Figure 9 presents the relationship between excess N as measured and as calculated for the transit time for 15 m or the unsaturated zone. The measured excess N was the measured NO_3^--N expressed as ppm in the dry soil times the total weight of soil per 15-m depth or the depth to the ground water. Three bulk densities were used to calculate this total weight, and these three bulk densities were also used in calculating the volumetric water content, θ, that was used to calculate transit time T. Thus, for each bulk density a different transit time was involved. The calculated excess N was obtained from equation [2] using the average NO_3^--N concentration in the 3.3- to 15-m depth or to the ground water and D from Table 3. In each case, the basic data are the NO_3^--N concentrations, but two different routes are followed to arrive at the excess NO_3^--N, in kg/ha per year, available for leaching by drainage waters. These relatively high correlations and the near 1.0 slope between these two methods of estimating excess N suggest that the data for transit times, leaching fractions, drainage volumes, and water intake volumes are reasonable and that the N balance data are realistic.

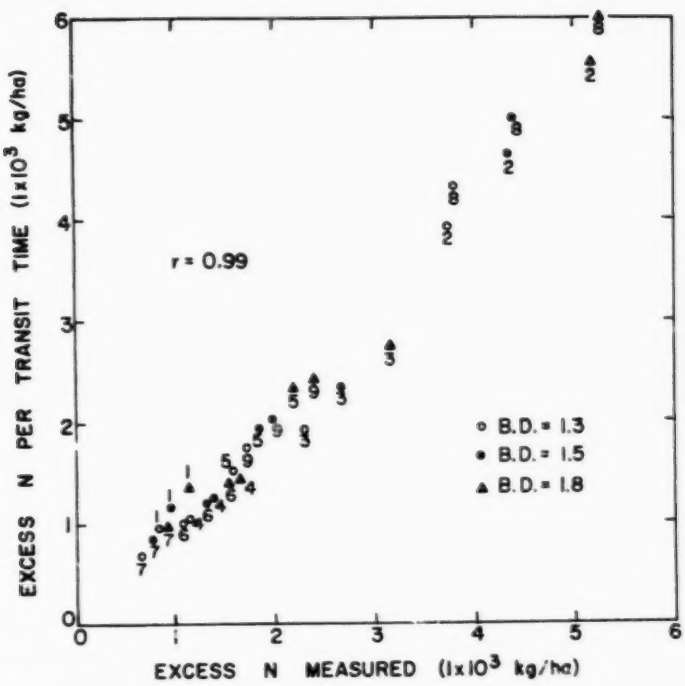


Figure 9. Relationship between excess N as calculated from equation [2] per transit time as calculated from equation [3], and the measured NO_3^--N excess in the soil for three bulk densities. The correlation coefficient is for a B.D. of 1.8. The number identifies the site.

SECTION VII

DISCUSSION

Citrus

Fruit removal by citrus varies from about 20 to about 60 kg/ha per year, respectively, for mediocre yields and high yields; maximum yields would remove about 100 kg (9). At a rate of N inputs of 150 kg/ha per year these differences in yield could result in substantial differences in the NO_3^--N concentrations in the water in the unsaturated zone at any given value of the drainage volume. Thus, high production is an important factor in reducing the movement of NO_3^- to the ground water.

Judging from the data presented for N balances, the estimates of leaching fractions, volumes of drainage water and transit times for water and NO_3^- are realistic.

Fertilizer practice for citrus in Southern California is based on leaf analysis standards such that the N input is adjusted to maintain 2.4 to 2.6 per cent in leaves from nonfruiting terminal growth, using samples taken in August or September (3,4). The usual rates of N vary from 100 to 150 lb/acre per year or 112 to 168 kg/ha per year. These rates combined with high production and leaching fractions of 0.35 or more could lead to a drainage water having considerably less than 20 ppm NO_3^--N. Treatments 1 and 6 with rates of fertilizer N of 168 kg/ha per year during the past 7 years showed 21 ppm of NO_3^--N in the soil solution at leaching fractions of 0.36 and 0.40, respectively.

Thus, the citrus industry in Southern California seems to have adjusted its fertilizer input to a level that, when combined with good water management for maintenance of low salt levels in soils and with high yielding trees, does not leave a high NO_3^- load in the drainage water. However, some doubt exists that the drainage water from lands in Southern California that are used for citrus production will have less than 10 ppm NO_3^--N. Thus, to meet the U. S. Public Health Service standards for NO_3^- the drainage will need to be diluted with low NO_3^- waters from other sources.

Row Crops

The high leaching losses of N associated with intensive irrigation of crops with shallow root systems may be one of the reasons for applying high rates of N on some vegetables. Most vegetables are grown on sandy and sandy loam soils in which conditions are not favorable for denitrification. However, for some crops like celery, potatoes, and strawberries which are irrigated frequently (sometimes every two days

with potatoes) sizable denitrification could occur even in profiles without significant textural discontinuity. Under these conditions, drainage water could have low NO_3^- levels.

The fertilization rates for row crops, particularly the vegetables, have increased considerably during the last four decades, with the peak in the early 1960s. For example, in the Santa Ana Drainage Basin which includes parts of Riverside, San Bernardino, Orange, and Los Angeles counties, the amount of N used per unit area in vegetables has increased more than five times since 1930, but, the removal of N per unit area of land by the harvested portions increased less than three times. During this same period, the area in the basin used for vegetable production decreased about 30 per cent. Thus, while this practice increased the yield, it also increased the potential for excess N in the soil which becomes available for leaching to the ground water. However, there was a declining trend in N use during the last ten years. The current recommended rate for N for most vegetable crops supplies about 135 kg N/ha above that removed in the harvested portions. Thus, four to twenty years hence, if recommended rates are used, the concentration of NO_3^--N in the solution at the 15-m depth in the basin would be about 22 ppm for a leaching volume of 60 surface cm/year or 44 ppm for a leaching volume of 30 cm/year. These NO_3^- levels, however, could be reduced by denitrification. Obviously, in all but one of the fields studied for this report, the combination of excess N, leaching volume and net mineralization or denitrification gave NO_3^- concentrations higher than these expected values.

Thus, the current fertilization practices on the row crops, especially for vegetables, seem to require some measures to reduce the NO_3^- load in the leaching water. This could include a) the use of recommended rates, sources, and time of application of N; b) soil fertility evaluation before each cropping season/ and c) the use of proper amounts of water for maximum yields and additional water needed to maintain a suitable salt balance in the surface soil. The recommended rates of N application to most row crops and the amounts of N that can be recycled by optimum yields have been published earlier (5,6).

Further investigation on specific crops in many production areas will be required to determine the pollution potential of the fertilizer practices used in each growing area.

General

Apparently, the three equations in the approach section can be used to make estimates of NO_3^- concentrations in the unsaturated zone between the zone of root influence and the saturated zone. The equations work best in open-porous soil profiles where water saturation is unlikely and actually difficult to attain and where the organic N

pool has reached a constant level, i.e., no net mineralization or immobilization of N. The important factors in this approach are 1) the volume of the drainage water and 2) the yearly excess of N input over removal in harvested crops.

The approach used here can also provide estimates of denitrification in the field. However, the uncertainty here is the constancy of the organic N pool. If this pool gains or loses N during the experimental period, the estimates of denitrification will be in error by these gains or losses.

Transit times through the unsaturated zone suggest that the excess N in a surface soil in any one year might not be a contributor to the NO_3^- in well waters until many years in the future. If the transit distance or depth to the water table is 30 m, a time lag of from about 8 to 50 years is likely in the alluvial materials of the Santa Ana River Basin in which the studies herein reported were made.

The data presented here suggest that a useful general relationship exists between soil profile characteristics and denitrification. Water management should enter as an important factor in denitrification, but it does not show clearly in this work primarily because of a lack of a definition or of a meaningful description of this factor. In any event, the work herein reported suggests that research aimed at developing numerical values for the probable denitrification in soil profiles would be desirable.

SECTION VIII

ACKNOWLEDGMENTS

The support of co-investigators W. W. Jones, Professor of Horticulture, V. A. Hunsaker, and D. C. Adriano, Postdoctoral Fellows in Soil Science, F. H. Takatori, Research Specialist in Plant Sciences and O. A. Lorenz, Professor of Vegetable Crops, is gratefully acknowledged.

The interest of W. A. Cawley, Deputy Director, Program Management Division, and J. W. Keeley, Chief, National Ground Water Research Program, of the Office of Research and Monitoring of EPA is acknowledged with sincere thanks.

Preceding page blank

SECTION IX

REFERENCES

1. Adriano, D. C., Pratt, P. F., and Bishop, S. E., "Nitrate and Salt in Soils and Ground Waters from Land Disposal of Dairy Manure," Soil Science Society of America Proceedings, 35, No. 5, pp 759-762 (1971).

2. Bingham, F. T., Davis, S., and Shade, E., "Water Relations, Salt Balance, and Nitrate Leaching Losses of an 840-acre Citrus Watershed," Soil Science 112, No. 6, pp 410-418 (1971).

3. Embleton, T. W., and Jones, W. W., "Leaf Analysis - A Tool for Determining the Nutrient Status of Citrus," Proceedings Soil Plant Diagnosticians, 1:pp 160-169 (1964).

4. Jones, W. W., and Embleton, T. W., "Development and Current Status of Citrus Leaf Analysis as a Guide to Fertilization in California," Proceedings First International Citrus Symposium 3, pp 1669-1671 (1969).

5. Lorenz, O. A., "Nutrient Uptake by Vegetable Crops," In Proceedings Sixteenth Annual Fertilizer Conference of the Pacific Northwest, Salt Lake City, Utah, pp 19-25 (1965).

6. Lorenz, O. A., and Bartz, J. F., "Fertilization for High Yields and Quality of Vegetable Crops," In L. B. Nelson (ed.) Changing Patterns in Fertilizer Use, Soil Science Society of America, Madison, Wis., pp 327-352 (1968).

7. Nelson, L. B., "Research Needed to Resolve the Plant Nutrient-Water Quality Issue," In O. P. Engelstad (ed.) Nutrient Mobility in Soils: Accumulation and Losses. Soil Science Society of America Publication No. 4, Soil Science Society of America, Madison, Wis., pp 75-81 (1970).

8. Pratt, P. F., and Chapman, H. D., "Gains and Losses of Mineral Elements in an Irrigated Soil during a 20-Year Lysimeter Investigation," Hilgardia 30, No. 16, pp 445-467 (1961).

9. Smith, P. F., "Citrus Nutrition," In Norman F. Childers (ed.) Fruit Nutrition, Somerset Press Inc., Somerville, N. J. (1966).

10. Stewart, B. A., "A Look at Agricultural Practices in Relation to Nitrate Accumulation," In O. P. Engelstad (ed.) Nutrient Mobility in Soils: Accumulation and Losses. Soil Science Society of America Special Publication No. 4, Soil Science Society of America, Madison, Wis., pp 47-60 (1970).

Preceding page blank

11. Stout, P. R., and Burau, R. G., "The Extent and Significance of Fertilizer Buildup in Soils as Revealed by Vertical Distributions of Nitrogenous Matter Between Soil and Underlying Water Reservoirs," In N. C. Brady (ed.) Agriculture and the Quality of our Environment American Association for the Advancement of Science, Publication 85, Washington, D. C., pp 283-310 (1967).

12. Thomas, G. A., "Soil and Climatic Factors which Affect Nutrient Mobility," In O. P. Engelstad (ed.) Nutrient Mobility in Soils: Accumulation and Losses. Soil Science Society of America, Special Publication No. 4, Soil Science Society of America, Madison, Wis., pp 1-20 (1970).

SECTION X

PUBLICATIONS AND PATENTS

Patents

None

Publications

Pratt, P. F., Jones, W. W., and Hunsaker, V. E., "Nitrate in Deep Soil Profiles in Relation to Fertilizer Rates and Leaching Volume," Journal of Environmental Quality, 1, No. 3, pp 97-102 (1972).

SECTION XI

GLOSSARY

Denitrification - The conversion by microbiological reduction of NO_3^- to N_2 or oxides of N that escape to the atmosphere.

Drainage Volume - The amount of water that moves from the root zone of plants. It is usually expressed as surface cm.

Evapotranspiration - The sum of the water used by plants and that evaporated from the soil surface.

Immobilization - The incorporation of N into organic forms from the inorganic forms in soils.

Leaching Fraction - The volume of drainage water expressed as a fraction of the volume of the irrigation water that infiltrated into the soil.

Mineralization - The conversion of N from organic forms to the NH_4^+ or NO_3^- forms.

Organic N Pool - The organically bound N in the soil profile.

Root Zone - The depth of soil that is permeated with plant roots, or the depth of soil that is influenced by the root system of plants.

Soil Profile - The sequence of layers or horizons or lack thereof within the 2-m depth of surface of the earth.

Transit Time - The time that drainage water takes to move a given distance in the unsaturated zone.

Unsaturated Zone - The zone between the zone of rooting of crop plants and the saturated zone at the top of the water table. Water movement in the unsaturated zone is by unsaturated flow.

Preceding page blank

SELECTED WATER RESOURCES ABSTRACTS

INPUT TRANSACTION FORM

W

April 1972

Nitrate in the Unsaturated Zone under Agricultural Land

P. F. Pratt

Department of Soil Science and Agricultural Engineering
University of California
Riverside, Calif. 92502

16060 DOE

16060 DOE

Environmental Protection Agency

Six treatments from a fertility trial with citrus , four commercial citrus groves and nine row-crop fields were studied to assess the effect of fertilizer N on the concentrations of NO_3^- in the unsaturated zone between the root zone and the saturated zone. Nitrate-N concentrations of 21 to 70 and 36 to 123 ppm in the water in the unsaturated zone were found for citrus and row crops respectively. The main factors were 1) the difference between N input and crop removal, 2) drainage volume and 3) soil profile characteristics that apparently control denitrification. In soil profiles having no layers that restrict water movement and in which the net change in the amount of N in the organic pool was essentially zero the amount of N input minus crop removal expressed as NO_3^- in the drainage water provided a reasonably reliable estimate of the NO_3^- concentration in the solution of the unsaturated zone. An estimate of transit time for drainage water through the unsaturated zone provided a means of calculating a field N balance.

This report was submitted in fulfillment of Grant No. 16060DOE under the sponsorship of the Office of Research and Monitoring, Environmental Protection Agency.

crops, denitrification, drainage water, evaporation, fertilizers, leacning, nitrates, nitrogen cycle, soil profiles, soil water movement, unsaturated flow, zone of aeration

V. B.Group 16

P.F.Pratt

University of California